

Connecting Electroweak Symmetry Breaking and Flavor: A Light Dilaton \mathcal{D} and a Sequential Heavy Quark Doublet Q

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As LHC Run 2 enters full steam, it may be time to reflect and make sure we have gotten everything right with Run 1 data. The 125 GeV boson is quite consistent with the Higgs boson of the Standard Model (SM), but there is a challenge from Anderson whether this particle is in the Lagrangian. The combined analysis of ATLAS and CMS claims 5.4σ measurement of vector boson fusion (VBF) production that is consistent with SM, which seemingly refutes Anderson. We caution, however, that VBF measurement is too important to be imprudent in any way, and gluon-gluon fusion with similar tag jets must be *measured* concurrently, which can be achieved at LHC Run 2. Only then can we truly test the dilaton possibility, the pseudo-Goldstone boson of scale invariance violation. We illustrate electroweak symmetry breaking by dynamical mass generation of a sequential quark doublet Q via its ultrastrong Yukawa coupling, and argue how this might be consistent with a 125 GeV dilaton, \mathcal{D} . The ultraheavy $2m_Q \gtrsim 4\text{--}5$ TeV scale explains the absence of New Physics so far, but the mass generation mechanism shields us from the UV theory for the strong Yukawa coupling. Collider and flavor physics implications are briefly touched upon.

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I. HIGGS, ANDERSON, AND ALL THAT

Spontaneous symmetry breaking (SSB) was introduced into particle physics by Nambu as cross-fertilization from superconductivity (SC). In an explicit model with Jona-Lasinio (NJL), Nambu illustrated [1] how the nucleon mass m_N could arise from dynamical chiral symmetry breaking ($D\chi SB$), with the pion emerging as a pseudo-Nambu-Goldstone (NG) boson. Subsequent work lead to the BEH mechanism [2, 3] of electroweak symmetry breaking (EWSB), which became [4, 5] part of the Standard Model (SM). The recently discovered 125 GeV boson [6] seems consistent with the Higgs boson of SM by every count. This has in turn stimulated condensed matter physicists to pursue their own “Higgs” mode.

As reported [7] in early 2015, a “Higgs” mode was observed in disordered SC films near the SC-insulator quantum critical point, far below the 2Δ double-gap threshold, where Δ is the “energy gap” of the SC phase (which was always maintained). This “light Higgs” mode is in contrast with “amplitude modes” around 2Δ that were claimed long ago [8]. Anderson, who originated the non-relativistic version of the BEH mechanism, praised [9] Nambu for elucidating [1] the dynamical generation of m_N , a “mass gap”, by drawing analogy with SC. In the NJL-type of models, a scalar boson would be an “amplitude mode” with mass $\sim 2m_N$. Anderson turned thus to challenge particle physics [9]: “If superconductivity does not require an explicit Higgs in the Hamiltonian to observe a Higgs mode, might the same be true for the 126 GeV mode?”, hence jesting “Maybe the Higgs boson is fictitious!”. He then stressed the importance of Ref. [7], as “it bears on the nature of the Lagrangian of the Standard Model”. As the person who coined the word “emergent” for phenomena that are not inherent in the Lagrangian, he is challenging the elementary nature of the 125 GeV boson.

What do we really know about the 125 GeV boson? If it is not the Higgs boson H of SM, then what else could it be? In this paper, we revamp the idea that the observed boson could still be a dilaton \mathcal{D} from spontaneous scale invariance violation. We argue that this can be truly excluded only by data-based simultaneous measurement of both the vector boson fusion (VBF) process and gluon-gluon fusion (ggF) plus similar tag jets. This is achievable with forthcoming Run 2 data at the Large Hadron Collider (LHC), despite the existing claim [10] already with Run 1 data. We then elucidate how EWSB might arise from *dynamical* mass generation of a sequential quark doublet Q through its ultrastrong Yukawa coupling, resulting in $2m_Q$ that is far above 125 GeV, which echoes the result of Ref. [7]. One should, of course, avoid directly matching a dilaton to the “Higgs” mode of Ref. [7].

The discovery of the 125 GeV boson is perceived as due to ggF production with observation in ZZ^* (two lepton pairs) and $\gamma\gamma$ channels, as illustrated in Fig. 1. Normalizing to SM by the coefficients c_g , v/f and c_γ (i.e. all would be 1 for H), what we observe is

$$(c_g v/f)^2 \simeq I, \quad (c_g c_\gamma)^2 \gtrsim I, \quad (1)$$

where $I \simeq 1$ in the minds of most people, which certainly holds for SM. However, treating c_g , v/f and c_γ as parameters and assuming v/f applies also to fermions, taking Higgs width modifications into account (where c_γ makes

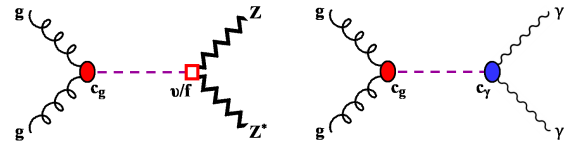


FIG. 1. Gluon-gluon fusion production and ZZ^* , $\gamma\gamma$ decay of the 125 GeV boson (dashed line).

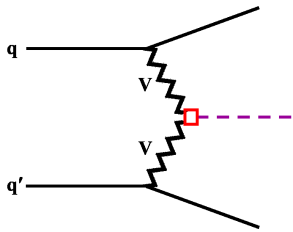


FIG. 2. Vector boson fusion production of 125 GeV boson.

negligible impact), one has

$$I \cong 0.91 (v/f)^2 + 0.087 (c_g)^2, \quad (2)$$

where, besides c_g , $v/f \simeq 1$, one also gets $I \simeq 1$ for $c_g \sim 3$, $v/f \sim 1/3$, where gg , rather than bb , is the predominant decay, while $|c_\gamma| \sim 1/3$ by Eq. (1).

Measurements so far are remarkably consistent with SM, but the individual coefficients clearly should be probed directly. If the 125 GeV boson is a dilaton \mathcal{D} , the (pseudo-)NG boson from SSB of scale invariance, then c_g and c_γ are determined by the trace anomaly of the energy momentum tensor, which would depend on the beta functions of QCD and QED, respectively, while v/f is the common factor as mentioned by Altarelli [11] as late as 2013: “The Higgs couplings are proportional to masses: a striking signature ...”, but “this is also true for a dilaton, up to a common factor”. That a dilaton could be confused for a light SM Higgs boson was stressed by Ref. [12] in 2008, before the advent of LHC. However, the example given was to have QCD and QED “embedded in the conformal sector at high scale”, hence $c_\gamma = -17/9$, and $c_g = 11 - 2N_{\text{light}}/3 = 23/3$, a case (and similar large values) that is definitely ruled out [13], causing many to write-off the dilaton. But in view of the Anderson challenge, the dilaton should be kept in mind and tested without prejudice, to the purist criteria of Elander and Piai [14] of keeping c_g , v/f and c_γ as parameters.

One might say that the VV coupling has already been measured with Run 1 data: the combined analyses of the ATLAS and CMS experiments together claim [10] 5.4σ measurement of VBF production, finding consistency with SM hence $v/f \sim 1$, which would run against the dilaton possibility. It is certainly true, and very important, that the VV coupling of the 125 GeV boson can be probed directly by the VBF process, as illustrated in Fig. 2. In the following, we begin with a critique of this 5.4σ claim, cautioning that it may still be premature. In this paper, we take the experimentally observed 125 GeV boson as the dilaton, without accounting for its true origins. We revamp the case for dynamical EWSB by ultra-strong Yukawa coupling of a sequential quark doublet Q , and elucidate why it might be consistent with the emergence of a dilaton. The approach shields one from the high energy completion behind this strong Yukawa coupling, including the origin of scale invariance breaking, hence the emergence of the dilaton itself.

II. CRITIQUE OF VBF “OBSERVATION”

We first note that the VBF measurements by ATLAS and CMS cannot be claimed as individually significant yet, as the cross section is $\sim 1/12$ of the leading ggF process. Combining datasets, when analyses are still limited by statistics, is suitably common. However, the combined analysis of LHC Run 1 data by ATLAS and CMS, claiming 5.4σ measurement of VBF process, has some weaknesses. We offer here some simple critique.

First, there is some issue of semantics. Recall the usage of Higgs-*like* for the 125 GeV boson, up to early 2013. By same token, so far one is really probing VBF-*like* production, rather than genuine VBF. This is because it is based on multivariate analysis of categorized data [10]. As V radiation is rather analogous to synchrotron radiation, it is effective only when each “spent” quark retains most of the initial parton momentum. But since m_V is sizable, genuine VBF requires two *very* energetic tag jets, which must be back to back, with large $m_{j_1 j_2}$ and large rapidity separation, and little color radiation in the rapidity gap. The categorized analysis is a compromise due to limited statistics. If statistics were sufficient, one would always cross-check with a high purity VBF selection that would beat ggF background down to a true minimum.

Second, with ggF the leading process, one needs a *data-based* measurement of both VBF production as well as ggF production with similar tag jets. The current VBF measurement relies on Monte-Carlo estimates for the latter, and *de facto* subtracting it [15]. It is not clear at present whether signal events are not really arising from ggF plus jets. Reduced resolution in the forward direction gives rise to further concerns. Third, the prominence of “Higgs boson” discovery means bias necessarily seeps into the analyses, especially after late 2013. And there is no good way to combine potential bias [16]. Finally, the 5σ claim has the connotation that *observation* is attained. But identifying the true source of EWSB is too important an issue to not keep the highest standards.

We conclude that one should await verdict on VBF from the much larger dataset that is already starting to arrive at LHC Run 2. Note that, despite some hints for $t\bar{t}H$ production in both Run 1 [10] and 13 TeV data [17], they are less significant. In view of Anderson’s challenge, we take the 125 GeV boson as an emergent dilaton, and turn to recount how a new sequential quark doublet Q could self-generate m_Q by its ultrastrong Yukawa coupling. This dynamical EWSB mechanism may *allow* a dilaton to emerge, but does not quite explain it.

The four generation (4G) model was supposedly “eliminated by the Higgs discovery” [18], because adding t' , b' to t in the triangle loop for ggH coupling would enhance the amplitude by ~ 3 , hence the cross section by 9, which is not observed [6]. But, there is nothing really wrong with 4G quarks, *except* this “Higgs” cross section, which could in fact be that of a dilaton, as we have just stressed. As already commented, $c_g \sim 3$, compensated by $v/f \sim 1/3$, also gives $I \sim 1$ in Eqs. (1) and (2).

III. THE YUKAWA COUPLING ENIGMA

Yukawa couplings of fermions are an enigma, but an elementary Higgs field is not needed to define them. There is a dynamical difference between electroweak (EW) theory vs. QED and QCD, where decoupling [19] is the rule. Nondecoupling of heavy quarks in EW processes, such as EW penguin effects in $b \rightarrow s\ell^+\ell^-$ [20], is rooted in the Yukawa coupling, which grows with mass.

As this author learned particle physics, SM began to enter textbooks, so we took the Lagrangian for granted. The SM Lagrangian has a built-in complex scalar doublet, and it was Weinberg who introduced [4] the Yukawa coupling for fermion mass generation.

By time of LHC turn-on, however, the weak vertex

$$\frac{1}{\sqrt{2}} g V_{ij} \bar{u}_i \gamma_\mu L d_j W^\mu, \quad (3)$$

had become firmly established by LEP and B factory data. Since all particles in Eq. (3) are massive, and since the longitudinal W_L propagates by the $\frac{k_\mu k_\nu}{M_W^2}$ factor, replacing W^μ by $\frac{k_\mu}{M_W}$ in Eq. (3) and using the Dirac equation, one gets [21]

$$\frac{1}{\sqrt{2}} V_{ij} \bar{u}_i (\lambda_i L - \lambda_j R) d_j G. \quad (4)$$

The weak coupling g cancels against $M_W = \frac{1}{2}gv$, and

$$\frac{\lambda_Q}{\sqrt{2}} \equiv \frac{m_Q}{v}, \quad (5)$$

is exactly the Yukawa coupling of the NG boson G , with both left- and right- chiral couplings emerging from a purely left-handed vector coupling! The point is: no Lagrangian is used, hence Yukawa couplings are experimentally established, and the longitudinal W_L is the “eaten” NG boson, without touching upon whether there is an elementary Higgs boson or field.

One may say that the above is nothing but the Goldstone theorem [22]. What we have elucidated is that all our knowledge of Yukawa couplings, including CKM matrix elements V_{ij} and the unitarity of V , are extracted through their dynamical, nondecoupling, effects. They arise from the NG bosons, without reference to an elementary Higgs doublet field, nor its remnant particle.

Anderson’s point, then, is that we need to make sure the 125 GeV boson is indeed the remnant of a complex scalar doublet in the SM Lagrangian, as we have discussed in previous section.

But Yukawa couplings are indeed an enigma: we know not what determines their values that range from $\lambda_{u,d} \sim 10^{-5}$ to $\lambda_t \cong 1$, while modulated by V_{ij} that exhibit hierarchical pattern, they are the sources of all known flavor physics and CP violation (CPV). With quark Yukawa couplings spanning 5 orders already, we now argue that raising by another order to the “extremum” value of $\lambda_Q \gtrsim 4\pi$, it could induce dynamical EWSB.

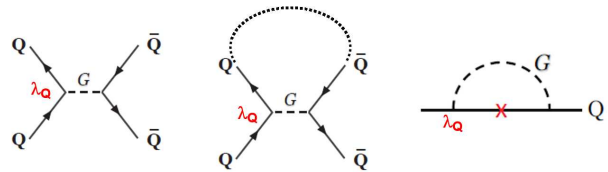


FIG. 3. (left) $Q\bar{Q} \rightarrow Q\bar{Q}$ scattering by exchange of NG boson G (or longitudinal V_L); (center) connecting Q to \bar{Q} across exchanged G ; (right) self-energy of Q by G loop, with mass generation illustrated by cross (\times).

IV. ULTRA STRONG YUKAWA-INDUCED EWSB AND THE DILATON

The 2008 accident delayed LHC start, but after 2010, search limits on $m_{b'}$, $m_{t'}$ quickly rose beyond the nominal “unitarity bound” [23] of ~ 550 GeV, but search continued for unitarity bound violating (UBV) 4G quarks. The heavy mass just implies very strong Yukawa coupling, and EW precision observables demand nearly degenerate [24] $t'-b'$, hence we denote as Q .

UBV implies bad high energy (H.E.) behavior for $Q\bar{Q} \rightarrow Q\bar{Q}$ scattering, which is dominated by G (i.e. V_L) exchange, as shown in Fig. 3(left). The range of interaction, $1/M_W$, becomes large compared with $1/m_Q$ for heavier Q . This runs against the intuition for short distance or UV remedy of the bad H.E. behavior, whether based on UBV or NJL folklore. Linking [21] a Q to a \bar{Q} across the exchanged G , Fig. 3(center), the $Q\bar{Q} \rightarrow Q\bar{Q}$ scattering turns into the self-energy of Q , where the exchange momentum q is summed over. This becomes a “gap equation” for generation of m_Q , the “mass gap”, as illustrated in Fig. 3(right), with the cross (\times) representing the self-energy function itself. A nontrivial solution would mean mass generation. As the chiral symmetry is the $SU(2)_L$ gauge symmetry, $D\chi SB$ means dynamical EWSB, which is in reverse of Weinberg [4].

The self-energy in Fig. 3(right) differs from NJL [1], which uses a dimension-6 four-quark operator that leads to a closed “bubble” with freely running loop momentum q but is independent of external momentum p , with cutoff Λ provided by the operator coefficient. In contrast, the NG boson loop of Fig. 3(right) manifests the long-distance nature, while the QQG coupling brings the external momentum p into the loop. Thus, the Yukawa-induced gap equation is different from NJL and more intricate. Note there is no scale parameter, as tree level $m_Q^0 = 0$ by gauge invariance.

To formulate the gap equation for mathematical solution, one needs to fix the range of integration for q . With no new physics found up to 1 to several TeV by summer 2011, the self-consistent and simplest ansatz [21] is to integrate q^2 up to $(2m_Q)^2$, such that the NG boson G in the loop is justified. By keeping λ_Q defined in Eq. (5) as a *parameter*, the scale v is brought in to make contact with experiment.

With this ansatz of integration limit being twice the generated mass m_Q , the gap equation was solved numerically [25] in the ladder approximation. Despite the urge to keep m_Q below TeV for sake of LHC phenomenology, a nontrivial solution demanded

$$\lambda_Q \gtrsim 4\pi, \quad (m_Q \gtrsim 2 \text{ TeV!}) \quad (6)$$

i.e. at “Naive Dimensional Analysis” (NDA) strong coupling [26] of 4π or higher [27]. $D\chi SB$, hence dynamical EWSB, can occur at “extremum” coupling strength! Shortly after submission, however, the 125 GeV boson was announced [6], so it took one and half years to get the work published [25], which was largely ignored.

The challenge from Anderson [9], however, throws a different light. In the Yukawa-dynamical EWSB, the self-energy sums over $Q\bar{Q} \rightarrow Q\bar{Q}$ scattering, hence is a *pairing mechanism*, much like Cooper pairs of BCS theory of superconductivity, which NJL tried to emulate [1]. We have already expounded the difference with NJL, and the numerical solution suggests EWSB occurs at NDA-strong 4π strength, hence perturbation has broken down absolutely [26]. For λ_Q consistent with Eq. (6), m_Q is generated, which means a $Q\bar{Q}$ condensate has formed, hence the exactly massless NG boson G is in fact a $Q\bar{Q}$ boundstate. All these can be viewed from the perspective of $Q\bar{Q}$ scattering in the massive world [28]. This dynamical mechanism can induce EWSB, without ever having an “explicit” Higgs in the Lagrangian. And much like NJL model, there should be “amplitude” modes, such as scalar bosons, around $2m_Q \sim 4\text{--}5 \text{ TeV}$.

We did not [25], however, anticipate a light boson far below $2m_Q$, but a light 125 GeV boson has *emerged*. In face of the challenge by Anderson, we take it to be a dilaton [29]. But how does it make sense in context?

Recall that our gap equation based on Yukawa coupling λ_Q has no scale, and contact with v was introduced self-consistently by ansatz of integration up to $2m_Q = \sqrt{2}\lambda_Q v$. Nontrivial numerical solution to our no-scale formulation, hence m_Q generation, would also seemingly break scale invariance. This may *allow* a dilaton \mathcal{D} to emerge [30], but we neither predicted it, nor do we know how $m_{\mathcal{D}}$ is generated. The dilaton should arise from the true origin of scale invariance violation, which we conjecture to be the theory of strong Yukawa coupling (explaining Eqs. (5) and (6)). In our approach, Yukawa couplings exist empirically from low energy EW studies, but a Higgs field was not invoked to define them. Note that $Q\bar{Q}$ condensation, as well as the integration limit of $2m_Q$, shield us from the actual UV theory, which is likely not far beyond the rather high $2m_Q$. We do not know what that is, except that it is strongly coupled, and likely conformal [12].

So, we have New Physics both within and beyond SM. Rather than the Higgs field, the agent of mass, or EWSB, is $Q\bar{Q}$ condensation via its own ultrastrong λ_Q . The 125 GeV boson is a dilaton \mathcal{D} that descends from some unknown UV sector; unlike the NG boson G , it cannot be a pure $Q\bar{Q}$ boundstate.

V. DISCUSSION AND CONCLUSION

Before discussing strong Yukawa coupling further, let us comment on flavor. Extending to 4G naturally affects flavor physics, such as $B_q \rightarrow \mu^+\mu^-$. The combined analysis of CMS and LHCb has established [31] $B_s \rightarrow \mu^+\mu^-$, albeit at $\sim 1\sigma$ below SM expectation. More intriguing is $B_d \rightarrow \mu^+\mu^-$, which has 3σ significance [31], but only because the central value is $4\times$ SM! This was our point [32] in refuting the verdict [18] on 4G. Experiments would surely pursue $B_d \rightarrow \mu^+\mu^-$, and the larger its rate, the earlier the discovery. But it would need considerably more data than at Run 1.

Another probe is the CPV phase ϕ_s in $B_s\text{--}\bar{B}_s$ mixing. The measured $\phi_s = -0.030 \pm 0.033$ [33] from LHC Run 1, which is dominated by LHCb, is fully consistent with SM, and further progress would take a few years. But this just means $|V_{ts}^* V_{tb}|$ and $\arg(V_{ts}^* V_{tb})$ are small. Keeping this constraint, we have shown [34] that enhanced $B_d \rightarrow \mu^+\mu^-$ can be accounted for, while $K_L \rightarrow \pi^0 \nu \bar{\nu}$ can be enhanced up to the Grossman-Nir bound of 1.4×10^{-9} , in correlation with some suppression of $B_s \rightarrow \mu^+\mu^-$. These flavor and CPV probes would no doubt be pursued with vigor, and could challenge the SM “Higgs” nature of the 125 GeV boson. Lastly, one should not forget the baryon asymmetry of the Universe (BAU), where the effective strength of CPV with 4G jumps by 10^{15} [35] or more over 3G, and should suffice for BAU. With such strong Yukawa coupling, one may have to rethink the issue of order of phase transition.

We return to discuss strong Yukawa before closing.

Just before Yukawa received the Nobel Prize, Fermi and Yang asked [36] “Are mesons elementary particles?” Defining “elementary” as “structureless”, they suggest the pion is an $N\bar{N}$ boundstate. They could not treat, however, the ultrarelativistic boundstate problem [28], and the π - N system took the path of QCD: hadrons are stringy $q\bar{q}$ states. But the well-known Goldberger-Treiman relation, $\lambda_{\pi NN} \simeq \sqrt{2}m_N/f_\pi$, is of same form as Eq. (5), while the $g_{\pi NN}$ coupling extracted from NN scattering is of order 14, the same strength as $\lambda_{\pi NN}$. It was this NDA-strong coupling that made sense of Eq. (6) for the G - Q system. The situation is actually more crisp than the π - N case: G is an exact NG boson, while Q , being sequential, is pointlike. What would be the origin, or underlying theory, of such strong Yukawa couplings? It must be spectacular like QCD, but not a sequel, (“something new, and geometric” [37]?), hence not technicolor. It is probably conformal [12].

Although the G - Q system should not be stringy, the similarity with the π - N system, in particular the NDA-strong coupling, suggests a simple analogy [38] that may be of phenomenological relevance: annihilation of $Q\bar{Q} \rightarrow nV_L$ into an EW fireball of NG bosons G (or V_L). Fermi had already speculated about it, but we learned since antiproton discovery that $p\bar{p}$ annihilates at rest into a fireball of 5 pions on average, emitted from a region of size $1/m_\pi$ at temperature $T \simeq 120 \text{ MeV}$, with Goldstone

behavior of soft-pion suppression. For the $Q\bar{Q} \rightarrow nV_L$ fireball [38], one replaces $\pi \Rightarrow V_L$, $1/m_\pi \Rightarrow 1/M_W$, and T slightly below EW phase transition temperature, which together with $2m_Q$ determines the mean multiplicity n of $\mathcal{O}(10)$ or higher. The Gaussian multiplicity distribution leads to little impact on few boson final states.

Eq. (6) implies $2m_Q = \sqrt{2}\lambda_Q v \gtrsim 4\text{--}5$ TeV, which seems out of reach at 14 TeV LHC, and observing the fireball may not be easy. But $Q\bar{Q}$ boundstates could help. If the V_L or NG boson G is a massless $Q\bar{Q}$ boundstate (Fermi-Yang redux!), the leading excitations [39] should be π_8 , ω_1 and ω_8 [40], where G would be π_1 in this notation. Although the hint for a 750 GeV $\gamma\gamma$ bump in 2015 data at 13 TeV has disappeared with more data [17], it motivates one to consider how low in mass could these first excitations be. For example, due to QCD repulsion, rather than attraction for π_1/G , the π_8 color excitation could have mass below 1 TeV, depending on its physical size. But they would have to be produced in pairs. Similar arguments can go for the less tightly bound ω_1 , as compared with π_1 , and its color excitation ω_8 , which is of particular interest, as it mixes with the gluon. Unfortunately, their nonperturbative boundstate nature makes the discussion rather speculative, as we have not solved the boundstate problem. We note that the η_1 , η_8 (as well as ρ and σ) states seem at best loosely bound [39] at $2m_Q$, hence it would not have been easy to account for a 750 GeV $\gamma\gamma$ bump. But if low-lying boundstates exist around TeV, rather than 4–5 TeV, the vector boson multiplicity of the fireball may be reduced, and production may be aided by mixing of ω_8 with the gluon.

In conclusion, LHC has entered Run 2 at 13 TeV collision energy, but New Physics is still no where in sight. In face of Anderson’s challenge that the 125 GeV boson

itself may not be in the SM Lagrangian, we have emphasized the possibility that it could still be the dilaton arising from scale invariance violation of some conformal sector at high scale. The SM “Higgs” nature of the 125 GeV boson should therefore be scrutinized free from any prejudice, and we must perform data-based, simultaneous measurement of VBF and jet-tagged ggF production with LHC Run 2 data. Heeding the cry, “Maybe the Higgs boson is fictitious!”, could turn out to be a second cross-fertilization from condensed matter physics. If VBF is found suppressed, then the 125 GeV boson could be a dilaton \mathcal{D} rather than H , with a heavy sequential quark doublet Q as source of EWSB. $Q\bar{Q}$ condensation by extremum-strength Yukawa coupling implies $2m_Q \sim 4\text{--}5$ TeV, which could explain the absence of New Physics so far at the LHC, motivating a higher energy collider. But high multiplicity vector boson production might appear at lower mass due to low-lying $Q\bar{Q}$ boundstates, and should be searched for. Corroborating evidence for a heavy sequential Q could come from enhanced rare decays such as $B_d \rightarrow \mu^+\mu^-$ and $K_L \rightarrow \pi^0\nu\bar{\nu}$, which are being pursued concurrently during LHC Run 2 period. Whether ascertaining VBF production or the pursuit of rare flavor physics, the issue may take a few years to pan out, but it could completely change our perceptions of electroweak symmetry breaking.

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- [28] The massless G as a Yukawa boundstate is astounding, and different from the pion. The γ_5 coupling nature requires large “lower components” of the Dirac spinors of Q and \bar{Q} , hence ultra-relativistic motion. The total inertial energy, at several $2m_Q$ (hence a rather compact object), would then have to be cancelled to zero by the ultrastrong Yukawa attraction.
- [29] We make no claim for understanding what is the light “Higgs mode” discovered far below the superconductor double-gap 2Δ in Ref. [7]. It should not be confused with our dilaton suggestion for 125 GeV boson.
- [30] A dilaton with v/f -diluted couplings added to our gap equation would not change our conclusions, but a light SM Higgs boson cannot be consistent. See Ref. [25]
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